Accelerated 3D Phase-Contrast MR Angiography using Time-Interleaved Autocalibration (TCAL)

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Introduction: 3D phase-contrast MR angiography (PC MRA) offers high-resolution visualization of vascular structures without contrast injection but requires long scan times to acquire 4 velocity-encoded measurements or "points" to measure flow in all directions. Data-driven parallel imaging acceleration methods such as GRAPPA [1] or ARC [2] demonstrate high-quality results even in challenging imaging situations [3]. Though the use of autocalibration offers robustness against motion and improved SNR, it reduces net acceleration due to extra autocalibration signals (ACS) collected within the scan. This scan time penalty is compounded in 3D PC MRA when ACS data is collected for each of 4 points. This work presents a time-interleaved autocalibration strategy (TCAL) to improve the imaging efficiency of 3D PC MRA.

Methods: Conventionally autocalibrated 3D PC requires a full set of calibration data for each velocity-encoded measurement, as shown in Fig. 1a (only the central k–space region is shown). Time-interleaved phase-encoding schemes such as TSENSE [4] and TGRAPPA [5] eliminate the need for ACS lines in dynamic imaging by merging data from adjacent time points; however, the shifting sampling pattern imposes a different phase on the aliased signal at each point [6] that could interfere with phase-sensitive PC reconstruction. Instead, we propose a TCAL scheme: the accelerated sampling pattern remains the same for all points, but a different subset of ACS lines is acquired at each point (Fig. 1b). Merging ACS lines across all points creates a full calibration data set that can be used for all points, thus achieving a 4-fold reduction in ACS acquisition time and similar SNR per point. For a similar scan time reduction with conventional autocalibration, a reduced ACS data set would be required (Fig. 1c). The theory underpinning the TCAL approach is that magnetization in PC imaging does not vary significantly between points; by definition, the only expected signal difference is the phase of the blood due to velocity-encoding (neglecting eddy currents, etc). Thus k-space data from multiple points could be merged for calibration.

Volunteer brain data was acquired at 1.5T (Signa HDx, GE Healthcare) using an 8-channel head coil and a balanced 4-point 3D PC sequence (V_{enc}=50cm/s). For this feasibility study, data was 2x accelerated along only 1 phase-encode direction, and ARC reconstruction (kernel size=3x7) was performed with: 1) conventional autocalibration with a calibration region of width 24 (per point) for a projected calibration time of 38s; 2) TCAL with non-overlapping calibration regions of width 6 (per point) for a calibration time of 9s; and 3) conventional autocalibration with a reduced calibration region of width 6 (per point) for a calibration time of 9s. All ACS data was included in the final images for improved SNR and image quality.

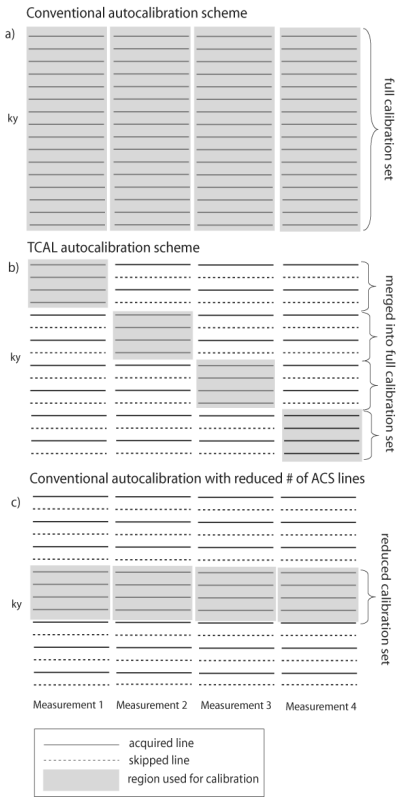

Fig. 1. Autocalibration schemes for 1D-accelerated 4-point 3D PC MRA. Only the central k-space region used for calibration is shown.

Results: Fig. 2 shows maximum intensity projections (MIPs) of reconstructed 3D PC MRA data. The MIP reconstructed with TCAL (Fig. 2b) results in comparable SNR and quality as conventional autocalibration (Fig. 2a), despite a 29s decrease in projected scan time. The MIP reconstructed with reduced autocalibration (Fig. 2c), though it has the same projected scan time as TCAL, shows increased background signal and decreased vessel conspicuity compared to (a) and (b) (arrows). This may be attributed to the fact that the reduced calibration region contained an insufficient number of training examples for the reconstruction, resulting in residual aliasing and phase errors. Axial and coronal MIPs of TCAL data (Fig. 3) show good image quality in all planes.

Discussion: This work demonstrates the feasibility of TCAL time-interleaved autocalibration to improve the efficiency of 1D-accelerated 3D PC MRA. By sharing the calibration burden across velocity-encoded measurements, TCAL reduces calibration time by 4x while retaining compatibility with PC reconstruction, robustness to motion, and the ability to retain ACS lines. While an alternative approach would be to acquire a full set of calibration data for only 1 point, this would result in unequal SNR across points that could bias PC reconstruction [7]. TCAL could also be used to improve the efficiency of 2D PC as well as other phase-sensitive techniques such as temperature imaging where magnetization does not vary significantly between points. Extending TCAL to 2D-accelerated 3D PC MRA should result in greater net acceleration and help make 3D PC MRA an attractive non-contrast-enhanced vascular imaging option.

References: [1] Griswold MA et al. MRM 2002; 47:1202-10. [2] Beatty PJ et al. Proc ISMRM 2007; 1749. [3] Griswold MA et al. MRM 2004;52:1118-26. [4] Kellman P et al. MRM 2001;45:846-52. [5] Breuer FA et al. MRM 2005;53:981-5. [6] Madore B et al. MRM 1999;42:813-28. [7] Pelc NJ et al. JMRI 1991;1:405-13.

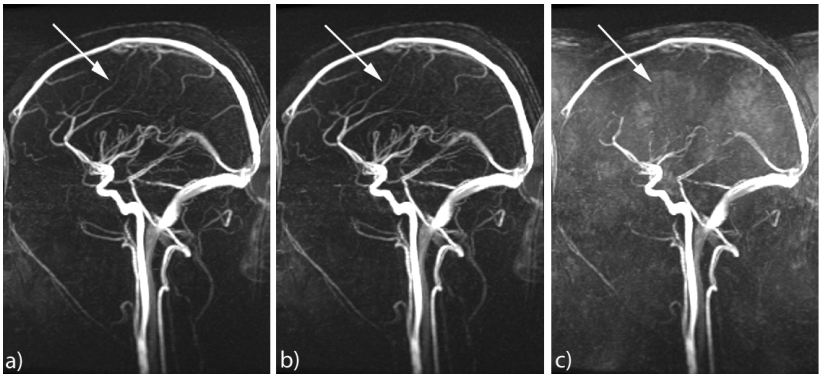

Fig. 2. Sagittal MIPs of accelerated 3D PC MRA. a) Conventional autocalibration (projected scan time = 205s). b) TCAL autocalibration (177s) reveals comparable image quality to (a). c) Reduced conventional autocalibration (177s). Increased background signal decreases vessel conspicuity compared to (a) and (b) (arrows). Resolution: 1.0x1.0x2.0mm^3. All images have the same W/L.

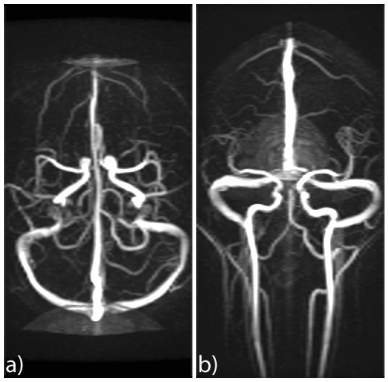

Fig. 3. a) Axial and b) coronal MIP reformats of accelerated 3D PC MRA data reconstructed with TCAL autocalibration.